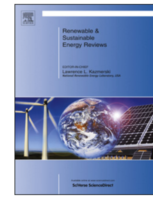
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The essence of future smart houses: From embedding ICT to adapting to sustainability principles

AmirHosein GhaffarianHoseini [a,*], Nur Dalilah Dahlan [a], Umberto Berardi [b], Ali GhaffarianHoseini [a], Nastaran Makaremi [a]

[a] *Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Malaysia*
[b] *Civil and Environmental Engineering Department, Worcester Polytechnic Institute, MA, USA*

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ABSTRACT

In the context of intelligent environments, the smart houses are often pointed as one of the main constituents of smarter living environments. This study attempts to theoretically analyze case models of smart houses in order to identify their essence and characteristics. The results show that the most significant intelligent values embodied in smart houses embrace technologies of the functional automation. In fact, smart houses are substantially intertwined with integrated ICT technologies which aim to ensure comfortable living environments. Despite the identified challenges, the proliferation of smart houses into urban areas requires an integration of them in the city for creating intelligent environments. As a result, the promotion and integration of smart houses with other smarter elements of cities could archive a significant enhancement of the quality of life and a stronger urban sustainability.

Contents

1. Introduction

Referring to the emerging information and communication technologies (ICT), the concept of smart is receiving a great attention worldwide. In particular, in the field of built environment, transversal

* Corresponding author. Tel.: +60 173178104.
E-mail address: amirhosein_ghaffarian_hoseini@yahoo.com (A. GhaffarianHoseini).

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studies highlight the fundamental role of smart houses and their significant impacts on the quality of user′s life [1–4].

In past decades, smart houses were often conceptualized as a creative dream for future communities [5]. However, recent scholarly studies confirm the penetration of smart houses into urban areas, confirming that the concept of smart house is gradually entering our lives [1,4]. This suggests the need for a smart adaptable built environment that is integrally equipped with interconnected new technologies, while considering environmental protection and social issues. This desirable smart built environment has shown to enhance significantly the quality of life for its users [6–8]. Accordingly, the creation of an intelligent built environment designed to ensure well-being of users based on intelligent technological values is promoted worldwide. This study argues that the achievement of users′ well-being requires an harmonization of environmental and socio-cultural values in the functional spaces of a house beside the integration of automated technologies [9–11].

This study analyzes the essence of smart houses and identifies appropriate technological values, which could be influential in enhancing the quality of living environments.

Smart houses as integrated living environments, which are equipped with intelligent technologies for automation of functions are targeted to become a common paradigm. In fact, the penetration of modern ICT into daily life, particularly in the houses, cannot be avoided [1,10].

Despite the main features of smart houses, which are undoubtedly beneficial for the enhancement of the quality of life, this study identifies a gap in the design of smart houses. In fact, the consideration of local characteristics as the environmental and socio-cultural values is often neglected during the concept, design and development of smart houses.

A recent study by Chan et al. [12] shows that fundamental issues during the design of smart houses regard cultural “acceptability” and “satisfaction”. Consequently, this research concentrates on the ‘intelligent technological values’ embodied in smart houses which have expectations for sustainability. In this study, rather than simply utilizing the smart houses as the prominent technological option, the concept of local smart houses through the incorporation of socio-cultural and environmental values of local region and the intelligent technological values is proposed.

2. Smart houses as part of intelligent built environments

Undoubtedly, the penetration of the concept of intelligent design into contemporary architecture can be perceived in many ways [1,13]. Smart houses are defined as modernized sensor-embedded residences with various integrated systems that are capable of communicating each other while being controlled remotely [3]. Basically, the concept of a smart house focuses on two constituents: it has to be fully integrated with ambient intelligence environments, and it has to base on the interrelations between the users and environments.

A smart house promises to create better living environments. This request is often accomplished with the promise to be effective for sustainability. A crucial step in doing so is to clarify the principles of sustainability in the built environment. The term of sustainability bases and enforces on interdisciplinary and incorporates the mutual enrichment of society, environment and economy. In this regard, due to the complexity of the versatile interpretations of sustainability, Berardi [14] attempts to elucidate the essence of sustainability of buildings. In this line, the findings illustrate fundamental aspects, relationships and circumstances to be taken into consideration such as ecological design principles, social attributes, environmental performances, lifecycle impacts, cultural responsiveness parameters, well-being criteria and economic concerns while reflecting the dependency of the interpretations to the time, context, size, level and social uncertainties as well as highlighting the interrelationships between the buildings and the context in a larger scale.

Beside the fundamental focus of smart houses on the utilization of intelligent technologies, these houses are also created to achieve sustainability based on the development of intelligent building design. In fact, the control of the energy performance while enhancing the life quality of users is among the main goals. Overstressing the evolutionary progress of environmental concerns in buildings, back to 1991, Sertorio [15] illustrates the potentials of an ‘intellectual’ house based upon the circumstances of control strategies, and automation approach in order to be harmonized with sustainability principles while leading to the reduction of temperature variations.

Moving forward, a detailed analysis of smart houses takes into account three main components: people (householders, users), products (facilities, equipment, devices, sensors and physical features) and processes (interrelations, performances). The creation of such house requires its harmonization in an intelligent built environment [9,10].

3. Significance of smart houses

The house allocates spaces for individuals or families to stay inside while being safe, relaxed and satisfied. It is the place where people carry out all their interactions such as eating, playing, sleeping, entertaining guests and many other functions. Thus, the house is comprised of functional spaces, which have a great potential for substantial influence on the quality of life.

The significance of housing embodies the concept for the amalgamation of residences in a certain area as an approach towards creating communities and neighborhood living styles. Nevertheless, it is argued that a major part of the users′ actual needs is in accordance with the functional spaces of their house. With respect to this fact, it is vital to consider the actual needs of users in their living area for ensuring the satisfaction level of users. This consideration requires embracing users′ environmental and social needs while reflecting awareness about current environmental poverty. In view of this contemplation, according to the aforementioned criteria, smart houses are a suitable alternative to the conventional housing.

In past decades, smart houses were often proposed as an innovative creation for future communities [3,5]. However, recent studies have argued that the concept of intelligent building design development is already bound up with versatile housing development policies [1]. According to Lertlakkhanakul et al. [16], smart houses must be equipped with advanced technologies for automation of functionalities. Likewise, Wood and Newborough [17] concentrated on home automation systems as a significant aspect of smart houses for the promotion of comfort, well-being, safety and energy saving actions. Therefore, this traditional idea of embedded intelligence within smart houses refers to the concept of functional automation [2,3].

In this sense, smart houses are entirely equipped with sensors and wireless networks as modernized sensor-embedded houses leading to an architecture that can meet all the needs of users [18]. Consequently, smart houses are developed to integrate new technologies and designs in order to bring a sense of well-being and a high quality of life to its users [6,7]. Referring to Ding et al. [2], the sense of security and comfort to the users through functional automation is a dominant peculiarity of smart houses.

Focusing on recent similar research based on case studies, with respect to the integration of local environmental values, Hansen

[19] explores a residential case study in Denmark which is efficiently designed and built to be sustainable and affordable with minimized negative environmental impacts. According to the analysis of this case, it is inferred that utilization of ecological materials and natural resources such as solar radiation could enable the building to generate sufficient power for its operations. In view of that, another recent study describes the integration of 'autonomous systems' such as the integrated rainwater collecting technique in houses as a move towards sustainable development. Similarly, in 1996, Lucia [20] concentrates on the circumstances of developing innovative buildings with reduced heat loss and enhanced thermal comfort. Through this evolution, in 2007, concentrating on buildings integrated with solar technologies, Lucia [21] develops the basis for adapting a building to sustainability principles with view to the geophysical energy flows. Beside these technological approaches towards environmental performance of buildings, the consideration of local trends embodied in the traditional houses as natural responds to the environment, is repeatedly cited. In this line, it is demonstrated that it is important to look at the essence of local environmental values as a basis of ecological design towards enhancing the life quality.

Therefore, the concept of local smart house is not only comprised of an integrated technological way to bring comfortable living environments for occupants but also it has to respond the local characteristics of the region encompassing the socio-cultural and environmental values.

"*Over the past 20 years many different buildings have been labeled as 'intelligent'. However, the application of intelligence in buildings has yet to deliver its true potential* ."[8]

According to current research on the significance of intelligent buildings, there are many interpretations of intelligent design [22]. The main interpretations mostly consider the crucial role of technology, without sufficient consideration of social, cultural and user interactions [22]. Other similar studies define intelligent buildings as automated buildings with flexibility, cost-efficiency and integrated technical performances [18,23]. However, a few studies criticize previous interpretations while arguing that intelligent buildings must be responsive to the user's actual needs [8,11].

Other studies suggest an inherent relation between the building and well-being of users [24,25]. It is believed that the functional spaces of buildings have a fundamental impact on the well-being of users [26]. Wong et al. [26] expresses that: *"Intelligent building accentuates a multidisciplinary effort to integrate and optimize the building structures, systems, services and management in order to create a productive, cost effective and environmentally approved environment for the occupants."*

Despite the previous interpretations of the concept of intelligent building, recent studies proclaim that it must create a successful combination, between the environment and the occupants [10]. Thus, they believe that an intelligent building must be able to adjust itself to the environment and the occupants. In line with this revision of the concept of intelligent building, which is still strongly ICT based, in the United Kingdom, definitions and interpretations are more focused on users' actual needs [26].

Looking retrospectively, it can be inferred that an appropriate interpretation of intelligent building design is required to consider all the issues that are influential in enhancement of contemporary houses. Other studies therefore propose a systematic strategy to achieve an appropriate definition of intelligent building based on defined quality issues [27].

Accordingly, the requirements are categorized in a way to ensure economic, environmental and socio-cultural concerns. As a result, it can be observed that 'Environmental Friendliness and Energy Conservation' and 'Culture', are the fundamental requisites for all intelligent building designs.

The new interpretation derived from the analysis of intelligent buildings highlights the need to integrate two main issues, 'technology' and 'user's actual needs' [28]. This new definition based on its corresponding modules enables designers to create environmentally and socio-culturally responsive intelligent buildings [28].

Recently, Clements-Croome [29] presents five interrelated modules as the basis of intelligent building design development:

Module 1: Concept, strategy and management;
Module 2: Building systems, architecture and people;
Module 3: Information technology and communication systems;
Module 4: Designing intelligence into buildings;
Module 5: Financial analysis and investment appraisal.

Analyzing these modules, it is clear that the developed framework by Clements-Croome [29] is inherently relevant and interrelated to the identified quality modules by Wong et al. [26]. The first module concentrates on a conceptual basis as a multi-attribute approach, with emphasis on environmental systems, management approaches and a linkage to people. The second module, as the target of this study, elucidates the role of congruity between people and architecture (intelligent buildings), and the third and fourth modules cover the impacts of technology applications and focus on the intelligent technological values. The fifth module, as the final issue, highlights the role of economic concerns during intelligent building design developments. The framework by Clements-Croome [29] is comprehensively covering the entire interrelated parameters for ensuring successful intelligent building design developments. Likewise, particularly focusing on the Module '*Building systems, architecture and people*', congruency between the house design and people demands including their socio-cultural and environmental values is needed.

In conclusion, it is argued that people inside smart house units will not feel a sense of belonging to the space due to the lack of a deep consideration of socio-cultural and environmental values of local region. It is suggested that it is an outstanding task to integrate the natural local life of local region including the discussed values into the design of smart houses. A review of the literature demonstrates that as a theoretical proposal, vernacular houses encompass spatial features that are based upon user's cultural values and the environmental characteristics of the region. On the other hand, literature reflects the intelligent technological values of smart houses as the essence of intelligent buildings. As a result, the concept of local smart house for enhancement of the quality of life is shaped and developed through a successful integration of the aforesaid values into the design of current housing developments in urban areas.

4. Review of smart house case models

Selected case models are explored to identify the most significant values of smart houses. Literature review highlighted that the essence of smart houses is characterized by the intelligent technological values utilized for functional automations.

In regards to the essence of smart houses, a recent study analyzes the smart houses in Europe, America and Asia with view to their functions, and identifies them based on the equipment, devices and objects. Moreover, Ding et al. [2] highlights that the essence of smart house is originated from the concepts of providing convenience, enhancing security and saving energy and all

these are addressed through embedded sensors and intelligent systems, integrated in the functional spaces.

Looking retrospectively to the essence of smart houses through focusing on selected smart houses, 'The Aware Home', developed at Georgia Institute of Technology, represents a successful attempt towards creating a smart laboratory house where users could be facilitated by intelligent technologies while being simultaneously tested and monitored by researchers. As a first-generation of smart houses, the concept was to apply ubiquitous computing systems to be linked to the entire functionalities and activities.

Similarly, 'The Gator Tech Smart House', developed at University of Florida, is another sample of smart houses which is fully integrated with intelligent systems that could be bought, installed, and utilized by end-users without the aid of technical engineers leading to an appliance-oriented environment. With view to context aware houses, 'Toyota Dream House Papi', developed in Japan, is another smart house equipped with ubiquitous computing systems and intelligent technologies for creating a smart adaptable environment; this house is not only utilized for home assistance services and automation of functionalities, but it is also dedicated to energy saving and environmentally friendly design. More recently, 'Ubiquitous Home', developed at National Institute of Information and Communications Technology (NICT), where the embedded intelligent systems are utilized to control all the house services while communicating with the occupants [30–32].

According to this overview of smart houses case models, it is inferred that their main significant is targeted for automation of functionalities. Below some of the considered case models are described.

4.1. The Gator Tech Smart House

The Gator Tech Smart House was designed and developed at University of Florida to provide a platform for experimenting and analyzing the application of intelligent technologies into a responsive house besides studying the responds of its users. This responsive living environment is based on pervasive computing, and it integrates sensors and actuators in intelligent computers. The focus of this 2500 sq ft. intelligent lab-house is on a limited target population including users with special needs and elderly people in order to assist them through the developed intelligent appliances for enhancing their quality of life (see Fig. 1).

The Gator Tech Smart House is designed for a single family and is aimed at testing, analyzing, verifying and validating the feasibility and effectiveness of intelligent integrated appliances for reating responsive intelligent spaces. According to Fig. 2, the layout of the Gator Tech Smart House is presented to show the main locations and focus of these integrated technological values.

There are various intelligent technological systems within the Gator Tech Smart House including smart laundry, projector, floor, displays, blinds, home security monitor, bed, closet, bathroom, mirror, front door, location tracking and mailbox. Through the use of a smart front door, the user can observe the visitors and communicate with them. Utilizing automated blinds in windows, these windows could be automatically adjusted for the preferred level of lighting, privacy and airflow. A smart bed could sense the sleeping patterns of users and adjust itself based on that while recording and tracking the sleepless nights. A smart laundry combined with a smart closet could notify the users of the time for using laundry while a smart closet can categorize the clothes and propose the best alternative of clothe based on monitoring the climate, weather temperature and other interrelated parameters. Similarly, a smart mirror located in the master bedroom could remind the user of important messages or notifying the user about health aspects. A smart bathroom is inclusive of smart flush, smart toilet paper sensor and smart shower. The amount of water, temperature and soap dispenser are automatically adjusted and utilized for even monitoring the cleanliness of user. Smart displays are integrated in all spaces of the house to be used for entertainment, information and media. The smart floor tracks the movement and location of house occupants and could even report the emergency once an elderly falls down (see Fig. 2).



Fig. 1. Samples of smart houses [16].

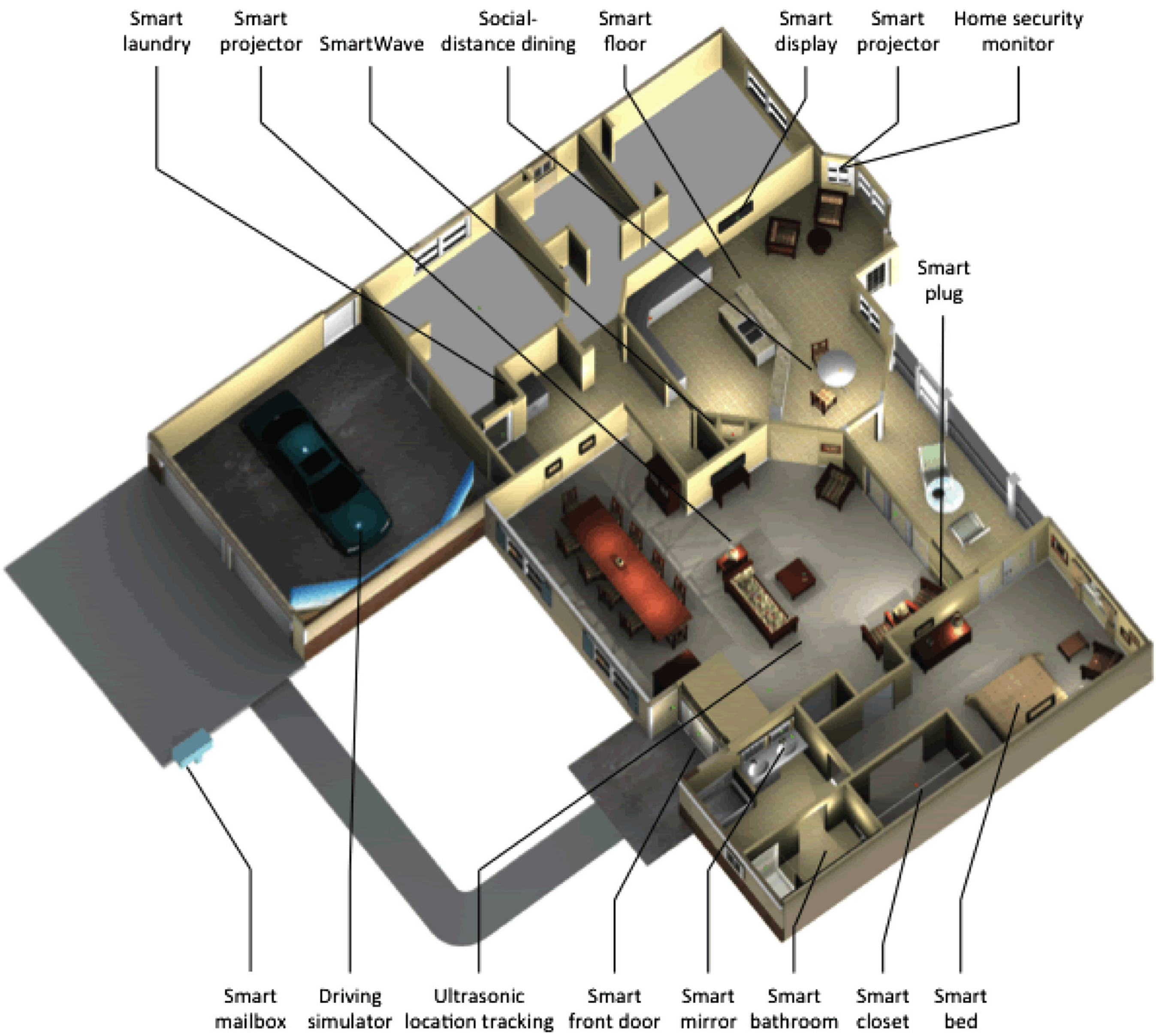


Fig. 2. The interior spaces of Gator Tech Smart House [61].

'The Gator Tech Smart House', developed at University of Florida, is therefore, fully integrated with intelligent systems that could be, installed, and utilized by end-users without the aid of technical engineers leading to an appliance-oriented environment.

It is inferred that all these technological values are utilized for house automation. Accordingly, it is highlighted that these prototypes could be integrated for creating smart living environments, not only for elderly and disabled users but also for everyone, in order to save the efforts and time of users. Reviewing various intelligent approaches utilized in this smart home, it is deduced that the main objective of this intelligent environment is to create 'assistive' and 'supportive' environment. Likewise, all these implementations are targeted to be operative and influential towards enhancement of the quality of life.

4.2. Matilda Smart House

With respect to the importance of independent living, Matilda Smart House is developed at University of Florida as an experimental environment for research implementations in the field of intelligent environments. It is theorized that it is necessary to create smart spaces within a house which are responsive and supportive. The Matilda Smart House is a 500 sq ft. experimental lab encompassing the main functional spaces of a house including kitchen, living room, bedroom and bathroom. This unique house is dedicated to new ideas and innovative concepts with view to creating smart living environment (see Fig. 3).

Concentrating on the types of integrated technologies and appliances, the main focus of this project is on the automation of daily needs of users. Similarly, the integration of intelligent technological values could be overwhelmingly influential in creating independent living for users.

4.3. Duke University Smart House

The smart house developed at Duke University is a 6000 sq ft. experimental laboratory for demonstrating the future of residential design in housing developments. Similar to the Gator Tech Smart House, the main philosophy as the basis of Duke University Smart House is that the integration of intelligent technological

values could enhance the quality of life. Likewise, it is theorized that a smart house must not be dedicated to elderly people and disabled users only. This smart dorm is contiguously utilized for education and research basing on technology integration (see Figs. 4 and 5).

Duke′s smart dorm is inclusive of common area, clean lab, media room, dirty lab, guest bathroom, as well as the second floor and basement. The second floor is used for private rooms while the basement is the embodiment of technological and mechanical systems (Fig. 5) and all these spaces are integrated with smart devices and appliances. There are two main objectives of Duke′s smart dorm which merits to be mentioned: *these are the concentration on energy efficiency in daily lifestyle and the integration of sustainably intelligent technological values.*



Fig. 3. The interior spaces of Matilda Smart House [53].

4.4. Drexel Smart House

Drexel Smart House is developed to be utilized as a 'living laboratory' for research and experiment in the field of intelligent environment. All the research implementations are focused on residential design, energy, smart appliances, and lifestyle. More importantly, similar to previous case models, it is dedicated to the quality of life. Reviewing the details of Drexel Smart House, it is identified that the sustainable approaches and green design are the ultimate concern of a smart house beside the house automations (see Fig. 6).

It is important to highlight that the Drexel Smart House is developed through the transformation of an old building into an intelligent living environment representing the possibility and feasibility of the intelligent technological applications into the rehabilitation of current houses.

4.5. MIT Smart House

In the MIT Smart House, it is highlighted that the digital technologies are rapidly changing the lifestyle of individuals and therefore, the way of communications, social interactions and



Fig. 4. The selected photos of Duke University Smart House [54].



Fig. 5. The exterior views and details of Duke University Smart House [54].



Fig. 6. The Drexel Smart House [55].

many other issues are highly affected. In view of that, it is necessary to apply the advanced technologies into the living environments, particularly the houses, to create a harmonization between the new lifestyle and the settings.

The MIT Smart House is developed to reflect the fact that a house must be responsive to the current and future demands and challenges. This interdisciplinary project is developed and created based upon the integration of intelligent technological values and smart devices to be responsive, adaptive while providing automated and assisted living spaces (see Figs. 7 and 8).

4.6. The Aware Home, developed at Georgia Institute of Technology

Looking retrospectively to the essence of smart houses through focusing on selected smart house models, 'The Aware Home', developed at Georgia Institute of Technology, represents a successful attempt towards creating a smart laboratory house where users could be facilitated by intelligent technologies while being simultaneously tested and monitored. The concept was to apply ubiquitous computing systems to be linked to the entire functionalities and activities. The essence of this house is derived from the idea that living environments must be 'aware' of their occupant′s demands and activities.

According to the design and technological implementations of Aware house, the use of technology for creating responsive environments has become a significant attribute. For instance, beside the application of sensors, the use of intelligent cameras is helpful for identification and reorganization of the users in order to address their needs through automated responds (see Fig. 9).

Analyzing its features, the model indicates that the use of context aware applications is fundamental for developing smart houses while the findings elaborates that the ultimate design and applications must be derived from the incorporation of technology and human oriented design basis. This could lead to the creation of harmony between the emerging technologies and the demands of users.

Similar to the previous case models, the Aware Home reflects the importance and necessity of the application of intelligent technological values for creating smart environments. Through the experimentation and analysis of the user′s preferences and satisfaction rates while residing in smart environments, the smart house is theorized as an enhancement of the quality of life.

4.7. The CASAS Smart Home project at Washington State University

The CASAS Smart Home is developed to provide an interdisciplinary research platform of intelligent environments. Reviewing the approaches and objectives, it is deduced that in essence, a smart home utilizes sensors to perceive and exploits actuators to respond to the environment.

There are two ultimate goals towards the development of smart homes as the embodiments of intelligent environments in the CASAS Smart Home project. The first goal is to maximize the user′s comfort through recognizing, discovering and tracking the user′s activities for the automated responses and the second one is to minimize the maintaining cost. Similarly, it is reflected that the estimation of the level of energy consumption must be inextricably bound up with the targets of smart homes. Accordingly, it is believed that these two goals could be considered significant principles for the quality assessment of intelligent living environments.

4.8. Smart Home Lab at Iowa State University

Smart Home Lab at Iowa State University is another significant example of the enhancement of 'quality of life' and 'independent living'. Specific features are the 'home automation' and 'home security'. In the Iowa State University Smart Lab, the application of intelligent appliances is highly contributing to user′s independence and life quality enhancement. For instance, smart doors are provided which only respond to the authorized users and could be opened or closed automatically according to user′s commands while ensuring the house security. Indeed, ISU Smart Home can



Fig. 7. The MIT Smart House (PlaceLab) [56].

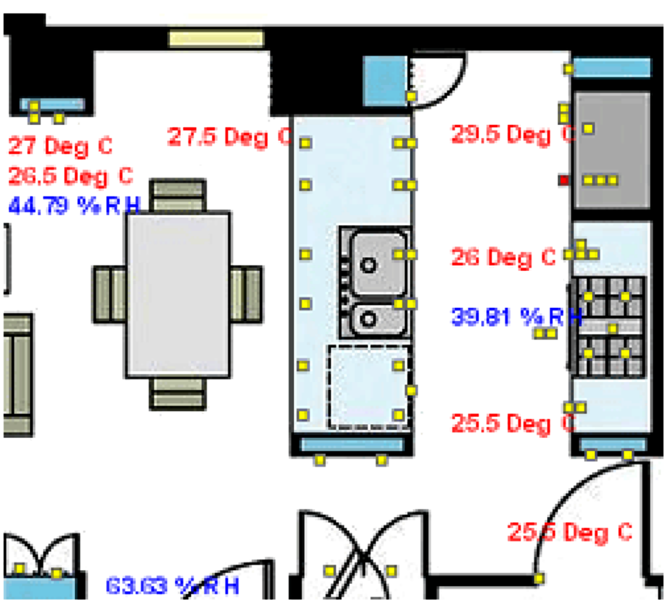


Fig. 8. Sensor data displayed on the PlaceLab plan layout [56].

easily identify the faces of authorized users and distinguish them from strangers and grant easy access to the users of the house. Utilization of intelligent light sensors is another significant feature for automatically illuminating the house environments based on user's preferences and activities.

This smart house encompasses smart environments that are equipped with smart devices and furniture. A smart bed monitors the sleep habits and prevents the users from any accidents such as falling from bed. Smart blinds could also be observed that are automatically functioning to be opened or closed according to the preferences of the users. Beside other smart environments and devices, there is a smart bathroom with automated functions for ensuring easy and independent daily activities.

4.9. *Toyota Dream House Papi*

With view to context aware houses, 'Toyota Dream House Papi', developed in Japan, is another smart house sample which is highly equipped with ubiquitous computing systems and intelligent technologies for creating a smart adaptable environment which is not only utilized for home assistance services and automation of functionalities, but also dedicated to the concept of energy saving and environmentally friendly design (see Fig. 10).

4.10. *National Institute of Information and Communications Technology (NICT) Ubiquitous Home*

More recently, 'Ubiquitous Home', developed at National Institute of Information and Communications Technology (NICT), where the embedded intelligent systems are utilized to control all the house services while communicating with the occupants. According to the elaborations on the essence of smart houses and the smart house samples, the main significant of smart houses as the intelligent technological values is targeted for the automation of functionalities.

5. Discussion

Referring to the studies about the development of smart houses, it is evident that they have been influenced by technological options in terms of ICT. These technological changes are the main source of impacts on lifestyle, social interactions, communications and the use of environments. Therefore, it is the crucial task of designers, architects and engineers to adapt the technological changes as the intelligent developments into



Fig. 9. The Aware Home — use of cameras and the observed segmented user [58].

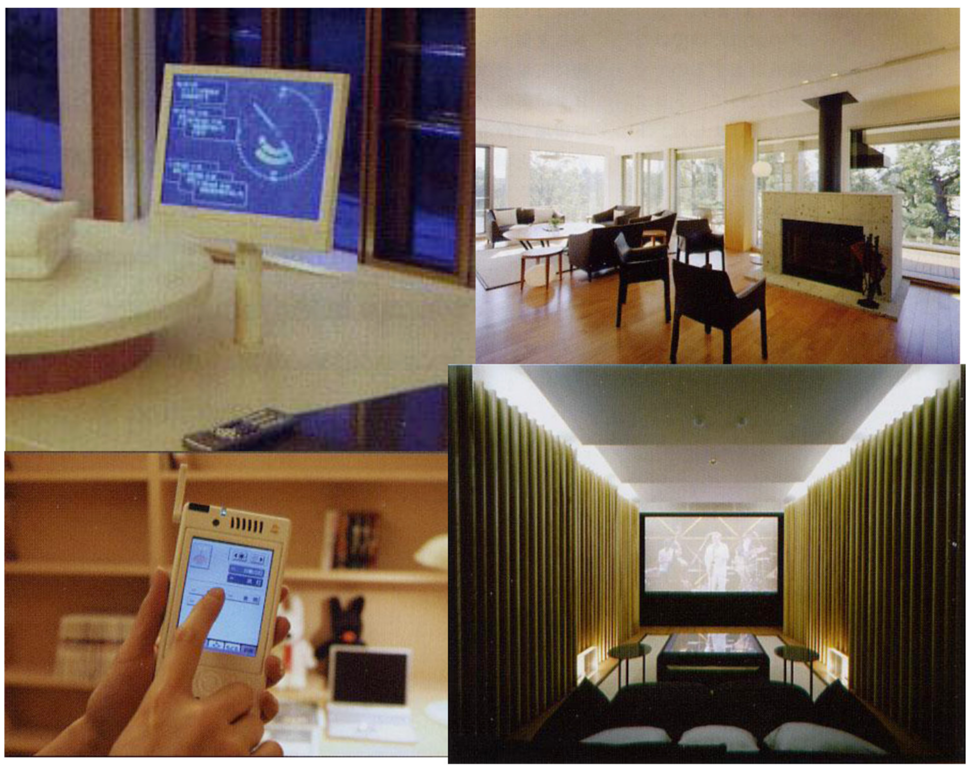


Fig. 10. Toyota Dream House Papi [59].

the design of living environments [33–35]. Similar to the 1980s, when the arrival of personal computers, there was a growing interest towards researching on the circumstances of utilization of personal computers at home and the respective impacts on the lifestyle and behavior of users. Accordingly, it is essential to concentrate on the interrelations between households, spaces, technologies and social behaviors to understand the most effective approaches for utilizing the new technologies. According to these viewpoints, the concept of smart house is developed to respond to the manifestation of new technologies through creating intelligent environments which are entirely bound up with embedded smart devices. In fact, the smart house proliferation could highly contribute to the harmonization of house and advanced technology for the sake of creating better living environment. At the same time, with view to the sustainable consideration of buildings, a smart house as a main constituent of intelligent building could be intertwined with sustainable features through creating energy saving opportunities. Thus, the social and environmental parameters are always the inherent part of an intelligent building beside the adoption of intelligent technological values. Supporting our discussion and overstressing the significant role of smart houses, Clements-Croome [36] states that "*An intelligent building can be described as one that will provide for innovative and adaptable assemblies of technologies in appropriate physical, environmental and organizational settings, to enhance worker well-being, productivity, communication and overall satisfaction.*"

In essence, it is inferred that there are substantial features and ultimate goals during the development of smart houses which could be utilized as a basic criteria. Referring to the theories regarding the contemporary houses, despite the manifestation of emerging technologies, the consideration of advanced technologies and intelligent features in the design of contemporary houses is not highly considered and therefore, there is not a harmony between the design of living environments in a house and the daily life of users which is intertwined with manifested technologies. Through studying and analyzing the main features of smart house models these could contribute positively to the improvement of user's housing satisfaction. In this regard, it is deduced that the intelligent technological values of smart houses as one of the main constituent of intelligent buildings is fully bound up with the main attributes of intelligent building systems leading to the

prominent role of functional automation [37]. An intelligent building is comprised of various intelligent building systems that are entirely designed for a natured interrelation, interconnection and control. "*Building interior layout system, Building facade system, Hydraulic and drainage system, Energy management system, Digital addressable lighting control system, Vertical transportation system, Security monitoring and access control system, HVAC system, Addressable fire detection and alarm system, Telecom and data system and Integrated building management system (IBMS)*" are main attributes of intelligent building design systems as supported by Wong and Li [37] and Clements-Croome [38].

In regards to this theory, the study by Wong and Li [37] developed a refined conceptual model of the intelligent building systems in order to enhance the efficiency, user′s comfort and environmental sustainability (see Fig. 11).

According to the main modules of intelligent building assessments in different regions including UK, USA, Canada, Hong Kong, Shanghai, Taiwan and Korea; there are some factors substantially important for regional assessments of smart houses (see Table 1).

Analyzing these viewpoints and comparing with literature review, it is denoted that there are main factors such as automation, functionality, comfort, security, efficiency, energy saving and system integration that are repeatedly cited and highlighted to be considered during the developments of intelligent living environments. Similarly, analyzing the smart house case study models, buildings are highly intertwined with smart devices. These smart devices could be divided into two categories as 'passive' and 'active'. Active devices encompass the control systems, which are directly utilized by users while passive devices are the sensors and receivers that are automatically functioning without the interference of users. Referring to the study by Doukas et al. [23], a conceptual framework for the development of intelligent environments is provided upon a philosophy that the respective criteria could be adapted to building′s requirements (see Fig. 12).

It is also crucial to highlight and overstress the significant role of smart houses as part of intelligent environmental sustainability. According to this theory, the incorporation of active features of the building with the intelligent passive technologies could significantly reduce the rate of energy consumption as an innovative approach towards sustainable developments. The manifestation and development of automation technologies in the design of houses has resulted in the development of houses with two significant benefits: energy efficiency and user′s comfort. [39–41].

The analysis of the smart house case models represent that the 'building automation system (BAS)', in particular functional automation of living environments within a house, is always a major concern as supported by various studies [42]. Likewise, it is highlighted that this automation is gradually becoming more engaged with the energy consideration. In this regard, during the analysis of smart house case models, a BAS integrator as Supervisory Control and Data Acquisition (SCADA) is shown representing the interconnections of different control systems and networks with view to the prominent role of functional automation.

According to the review of smart houses based on the inferences of participant′s viewpoints, it is deduced that there are four main themes of consideration as the basis of smart house cases. With view to the intelligent technological values, the 'functionality' is a substantial factor while considering the 'usability' and 'reliability' of functional design. In regards to the ethical consideration, 'privacy' and 'trust' are the main issues to be considered. Referring to the user perceptions, it is necessary to consider the issues of 'safety', 'independent lifestyle' and 'assistive design' during the design developments of smart houses. Regarding the role of marketing and policies, it is necessary to look into the

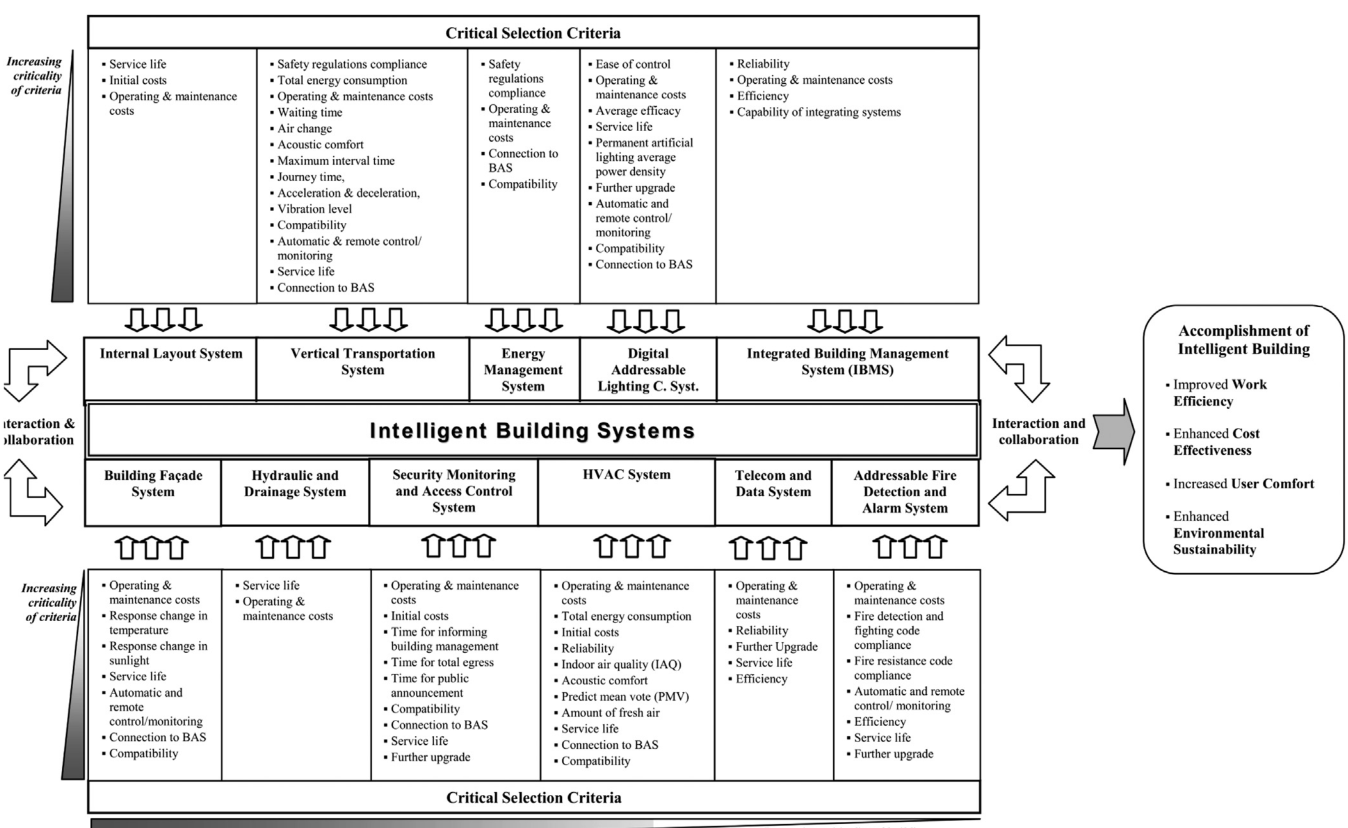


Fig. 11. A conceptual model [37].

Table 1
Criteria for intelligent buildings assessment [60].

Assessment clusters	Main modules by each assessment system					
	AIIB method (Hong Kong, China)	BRE method (UK)	CABA method (Canada/USA)	IBSK method (Korea)	SCC method (Shanghai, China)	TIBA method (Taiwan, China)
Architecture Engineering	Comfort Health and sanitation space High-tech image Safety and structure Working efficienc y	Built environment Functionality Responsiveness Suitability	Automati Comms Security Structure Systems	Architectural design Electrical system Info and comms Mechanical system System integration	Communication Earthing Facility control Fire accident control Int. integration Office automation Power supplySecurity Structured cabling	Health and sanitation Info and comms Safety and security Structured cabling System integration
Environment Economics Management Sociology Culture	Green Cost effectiveness Practice and security	Economic issues Property	Facility	Environment Property	Environment Facilities	Energy consumption

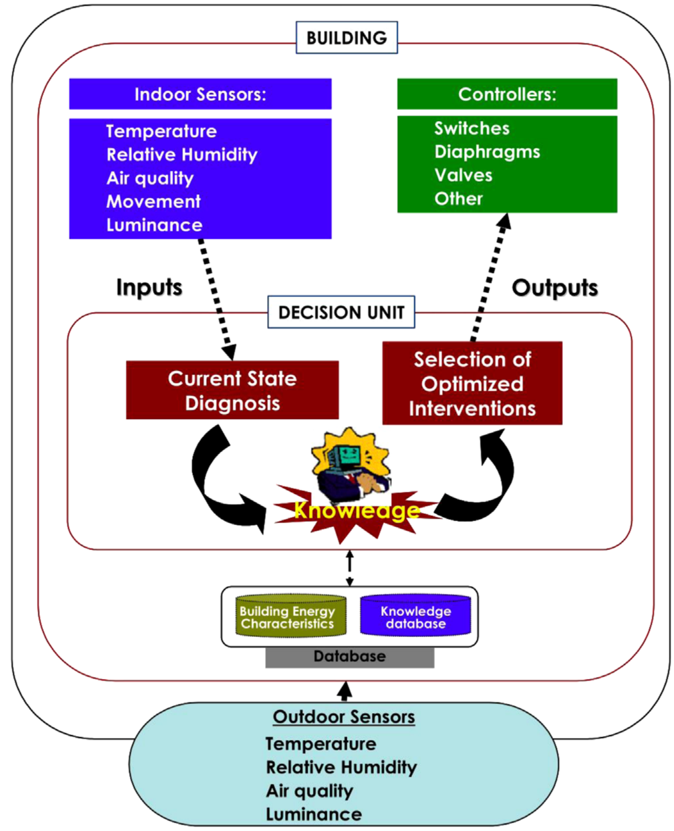


Fig. 12. The model's concept [23].

absence of policies with view to the smart houses, the access to the technology and its affordability [43].

According to the elaborated points, approximately, all the smart house cases are developed based on three main objectives, which are 'enhancement of the quality of life', 'improvement of comfort' and 'enhancement of safety and security'. Similarly, there are significant features that are the inherent parameters of smart houses for creating intelligent environments. Reviewing these features and comparing them with the recent scholarly researches, it is identified that the main intelligent technological value of smart houses is 'functional automation'. This automation, which is also called 'home automation', is feasible and operative for enhancement of comfort, safety, security and quality of life according to the integrated sensors, actuators and other smart devices. Indeed, the integrated smart devices, which are the basis of these intelligent environments, predict, recognize and control the movement and activities of users and automatically respond according to that occasion. With view to the selected case studies and the research outcomes, it is repeatedly reflected that a smart house as the embodiment of intelligent environments, could bring energy efficiency, independent living, privacy, safety, security and convenience to the life of inhabitants [35]. In this respect, 'people' are the main point of concern for the development of intelligent environments and therefore, the consideration of socio-cultural and environmental perspectives become overwhelmingly important, hence, this fact exhorts the integration of smart houses into the design of contemporary houses, particularly in newly developed urban areas. Despite the undeniable benefits of smart houses there are significant challenges. The research by Venkatesh [44] highlights some of the significant constraints as the challenges of smart houses. Accordingly, some of the main challenges are the unawareness of users about the benefits of smart houses, the complexity and difficulty of the utilization of these intelligent

systems and the respective costs. On the other hand, versatile studies have attempted to give insights and basic information towards the benefits and positive results of smart house developments while claiming the cost efficiency of smart houses. Many studies reflect that the interactions of users and smart devices must be minimized to the minimum level in order to ensure that the users could easily live in the intelligent environments without any complexity or difficulty.

Referring to the studies by Jeong [35], Jeong et al. [45] and Venkatesh [46], the categorization of an intelligent environment, which is an incorporation of technology and households, is provided based upon representing the interrelations between sub-environments, family members, activities and technological configurations (see Tables 2 and 3).

This framework is a basis for identifying the intelligent technological values of responsive environments through particular activities to the allocated sub-environments and users.

Overall, matching the results with the outcome of interrelated researchers including Clements-Croome [24], Aldrich [47], Hamill [48], Jeong [35] and Kofler et al. [41], it is highlighted that smart houses are significantly beneficial for environmental control and reduction of energy consumption with viewpoint to the sustainable design. Thus, expanding the potentials of smart houses, despite the focus of various studies on the benefits of smart houses for older adults and handicapped users [49,50], this study concludes that the fundamental objective of future smart houses must encompasses thoughtful consideration of all user′s demands. Furthermore, the smart houses improve the connections and communications between the users and the intelligent environments resulting in ensuring a better lifestyle which is independent and convenient and could bring relaxation, safety and security. It is also recommended that the use of automated functions based on task transfers through the interconnections of computers, smart devices and intelligent environments with focus on lighting, ventilation, windows and blinds movements is an essential phase of consideration. Likewise, the results indicate that the smart houses must be intertwined with the concept of energy-cost saving. Meanwhile, safety, security, warning, protection and control authority must be fully considered during the design of smart houses as other quality of life indicators. It is therefore reflected that a smart house could be significantly contributing towards ensuring the sense of relaxation through creating cozy spaces that are fully equipped with automated technologies. Supporting the analytical findings, De Silva [39] identifies the main focused constituents of smart houses through a state of the art review and accordingly, it is illustrated that the respective intelligent technologies are mainly utilized in smart houses for 'safety & security', 'health issues', 'supporting the children and elderly', 'enhanced energy performance', 'leisure and engaging activities', and consequently 'improved life quality'. Meanwhile, reviewing the most recent efforts for enhancement of the energy efficiency in buildings for development of future eco-cities as reported by GhaffarianHoseini et al. [51,52] and Berardi [62], the findings encourage future studies to focus on adapting the smart houses to the sustainability principles for achieving zero energy smart houses.

6. Conclusions

The study indicated that in past decades, smart houses were mainly conceptualized as a creation for future communities simply based on ICT. However, recent studies have argued that the concept of smart house is gradually entering our lives. Referring to the current research, it is inferred that the main focus is predominantly on the development and application of advanced

Table 2
The Interactions between users and integrated intelligent technologies in a Smart House [35,46].

	Sub-environments					
	Food management	Household maintenance finance	Leisure/recreation entertainment	Social/family communication	Work/employment	Family development/well-being
Family users of technology	Primarily adults (parents)	Primarily adults	Whole family	Whole family	Primarily adults	Children and adults
Household activities for technology use	Meal preparation and consumption, washing dishes, grocery shopping	Family shopping, cleaning, Tax preparation, family budget	Watching TV, holiday travel, movies, games	Telephone conversations, family communications, holiday reunion, Correspondence	Job-related activities, telecommuting	Children's education, adult education, family fitness dieting, holiday gathering
Configuration of household technologies	Kitchen appliances, automobile, ATMs, computer, home shopping (Online)	Washer dryer, automobile, ATMs, computer, online, home banking	TV, VCR, stereo, automobile, computer, multimedia, online services	Telephone answering machine, fax, computer/email, Internet, online services	Telephone answering machine, fax, automobile, computer, Internet	Typewriter VCR, telephone, computer, Internet

Table 3
The corroborated features of Smart Houses [35,57].

		Objective	Prediction for resident's needs by learning the resident's living patterns and actions
Adaptive house	Colorado Univ.	Scenario (example)	1. A resident comes home 2. A resident turns on (adjust) the lighting 3. Then, when the resident comes home tomorrow, the light will be turned on (adjusted) automatically 4. Repetition of this interplay
		Characteristics	1. Residential comfort system — Connection between temperature, lighting, ventilation, water temperature controls and resident's action patterns 2. Prediction and control — by learning the resident's action patterns, smart home system can predict the resident's next action and control the environment automatically
		Application	ACHE (Adaptive Control of Home Environments)
Aware home	Georgia Tech	Objective	Service development for the elderly based on human-like perception
		Scenario (example)	1. Displaying the action information of the elderly 2. Notifying the elderly the time for taking medicine and the things that happened right before now 3. Requesting help to outside when the elderly gets accidents or be in danger
		Characteristics	1. Specification of aware-home domain – suggesting a specific domain of application by specifying a target group such as the elderly and developing appropriate applications for the target 2. Context awareness and ubiquitous sensing – collecting the resident information by sensing or using camera, Sensors need to hide from the resident's sight or can be installed on human's body in wearable forms such as necklace or watch
		Application	1. AgingPlace — Action information of the elderly 2. Finding lost objects — Location information of the objects which the elderly can be easily forgetful of 3. Smart carpet — Resident's identification information by sensing the weight
House-n project	MIT	Objective	Building a customized house that include home system
		Scenario (Example)	To down the cost, the resident design their own home by using an easy design tool
		Characteristics	1. Adaptable – Customized environment — Customized home system (home networking, digital appliances, new construction materials) will be installed in home environment 2. Interactive user interface environment — Obtaining the resident action information by using sensors, then controlling digital appliances through home network by using these action information (i.e. interaction between the residents and their home is possible) 3. Architectural Design and Visualization Environment — Providing digital interfaces and design simulation environment
		Application	1. Home-based preventive medicine — Function to alarm for medicine or for heart attack 2. Energy/Resource consumption and comfort — To reduce energy consumption, function for energy control that adapted to the resident's action patterns 3. Universal controller — Remote control and integrating function for home appliances, development of interface that adapted to the resident
Easy living	Microsoft	Objective	Prototype development and appropriate technology development for intelligent environment where active communication is provided between human and human, human and computer, or human and device
		Scenario (Example)	1. If a resident tells a name that he/she wants to call, then EasyLiving can make a phone call instead of the resident 2. EasyLiving can provide the interface such that the task can be continued even when the resident moves to another place
		Characteristics	1. Self-aware space — Investigating the environmental information to provide appropriate reactions to the resident's requests 2. Casual access to computing — computing resources can be provided to the residents regardless of location and time 3. Extensibility — EasyLiving space can be extended along with adding new resources
		Application	1. Migrating windows — A task can be transferred between PCs 2. Contact anyone anywhere — the ability to transfer the message on the available resource nearby the resident 3. Child care assistant — the ability to notify the parents when a child or a pet is in a dangerous situation 4. Vision based home automation — lighting can be automatically adjusted when the resident read a book or the room is empty
Dream home	LG	Objective	Providing an environment as an intelligent agent for housewivesProviding a kitchen environment that the residents can control home appliances remotely through the Internet
		Scenario (example)	1. Video conversation with her husband to decide a dinner menu through the internet attached on refrigerator 2. Automatic ordering cooking materials for the dinner through the internet search 3. Automatic cooking by downloading cooking recipe for the dinner
			1. Washer or air conditioner may be able to notify the residents its problems by self-diagnostic-functions 2. Washer or air conditioner provides various operating modules based on the resident's preference
		Characteristics	Development of LNCP which is a communication protocol namely living network control protocol
		Application	Internet home appliances (e.g. Internet refrigerator, air conditioner, microwave, washer, cooker), dream home service, (e.g. menu providing service through the Internet, providing automotive cooking recipe for the selected menu, providing optimized operating modules)
Digital home	Samsung	Objective	Specifying four main domains for home living such as happy, amusing, surprising, and convenient living, Providing the residents the environment that can satisfy these four living themes
		Scenario (example)	1. Happy living — control the lightings and temperature, Providing a remote medical diagnostic service, Providing dining menus for the family automatically

Table 3 (*continued*)

			2. Amusing (Entertaining) living — building an entertainment environment by using HDTV and audio system 3. Surprising living — building an entertainment environment by using multimedia devices 4. Convenient living — providing remote control of home appliances from outside, providing GPS, GIS services in driving situation
		Characteristics	Connecting information of home appliances to home networkProviding integrated control or management of the connected environment
UbiHome	KJIST	Objective	Providing an infrastructure for management/administration of various sensors, context, and application by using computers distributed in the environmentTracking or notifying the resident's location, gesture, identity and intention as well as recognition of an object and its location
		Characteristics	1. Ubiquitous computing environment — (whereas the context produced by various sensors is administered by server in many smart home researches, UbiHome provides distributed computing environment such that the process dealing with sensors generates and administers contexts for itself.) 2. Intelligent environment — Tracking or notifying the resident's location, gesture, identity, and intention as well as recognition of an object and its location 3. Personalized environment — providing a customized or adapted home environment that reflects the resident's living pattern
		Application	1. Entrance control service 2. Automatic control of the resident's environment 3. Finding lost object 4. Danger preventing service 5. Universal controller 6. Gesture command controller

technologies as embedded in smart homes in order to ensure safety, security and comfort for elderly and disabled. Nevertheless, this study argues that the objectives of the retrospective attempts on smart houses are required to be substantially intertwined with the circumstances of creating sustainable living environments, green design and intelligent building systems. For this local or regional values are important for promoting an innovative approach towards higher quality of life. The need for a smart adaptable built environment that is equipped with new technologies, while considering environmental protection, and social issues, is evident. Reviewing current researches and case models regarding the interrelated issues of smart living, it is inferred that the current implications of smart houses are inherently bound up with the application of intelligent technologies utilized for automation and are limited to the role of technology as the embedded intelligence. However, it is argued that the essence of smart house and the breadth of research on embedded intelligence are not limited to the advance integrated technologies.

The notion of smart house must target for a harmony between architecture, people and environment and likewise, the harmony between the utilization of advance technologies and local characteristics of region. In this regard, the use of appropriate vernacular features of vernacular built environments as embodiment of smart living environments for creating local smart houses is promising.

Ultimately, the fundamental of intelligent buildings encompasses smart houses as being 'adaptable' and 'responsive'. It is indicated that an intelligent buildings must be adaptable and responsive to the long-term and short-term actual needs of users while dealing with the social and technological changes.

Local Smart House will have significant benefits including independent and assistive living, convenience, safety, privacy, security, energy efficiency, centralized control and remote access. This will result in enhancement of the quality of life for the occupants. In conclusion, the concept of local smart house could contribute successfully towards creating houses that are healthier, safer and more comfortable. The local smart house as a new alternative for better living will not be limited to a specific group as it could be designed to be dedicated to the users of any particular region. Likewise, it will be significantly effective in the sustainable development of cities through the use of energy saving appliances. Beside the low level of resource consumptions, the local smart houses are fully responsive to the socio-cultural background of users and the environmentally local attributes of the region.

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